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***Abstract*—Energy efficiency is one of the main challenges to be faced by mobile communications in the near future. The growth of the mobile communications market which is boosted by the increasing penetration of smartphones and laptops requires an increase of the network capacity and, consequently, a great leap forward also for the infrastructures. In this scenario, in order to reduce the operative expenditures, the network operators pay attention to energy saving strategies that may also contribute to the reduction of greenhouse emissions. In this paper the exponential smoothing technique is applied to forecast traffic in a given area considering daily and weekly variations. The availability of a reliable prediction of the future traffic values allows the adaptation of macro base station transmission power and the introduction of a sleep mode for micro base stations and permits to guarantee the requested network capacity while saving energy consumption. Results show the effectiveness of traffic forecast technique for capacity prediction and the usefulness of the proposed algorithms for energy efficiency maximization, affording very good performance, very close to the optimum one.**

I. Introduction

Current wireless communications deal with different objectives [1]–[5]. As for the mobile communication systems, the increasing of energy efficiency is one of the main actual and future challenges. The necessity to reduce the energy waste is driven by the willing to reduce the environmental impact of human activities and by the possibility to decrease significantly the operational expenditures (OPEX). Actually ICT industry is considered responsible of 2% of global CO_2 emissions [6] and its ecological footprint is foreseen to increase by a factor of three in 2020.

Nonetheless, the energetic bill is a very important expenditure also for ICT companies: in Italy the energy consumption of the main telecommunication company is responsible for the second national energy bill, that is to say the biggest after the national railway company [7]. The growth of the market which is due to the greater penetration of broadband services in everyday activities forces the operators to provide users a wide set of high data rate services: the growth of the number of mobile subscriptions, enforced by the proliferation of smartphones and laptop data connections, is foreseen to be about 7600 millions in 2014 with respect to the 2950 millions in 2009 [8].

Focusing on mobile wireless communications, [9] and [10] highlighted that the major contribution to energy consumption is due to the access network where about 50-60% of overall power is spent: in particular, the main contribution is due to the radio base station where the biggest term is the power amplifier (about 65%). Recently, in order to reduce the power consumption in the radio access network infrastructure, a lot of strategies have been proposed [11]–[15], some of which are supported by international research projects [16], [17], demonstrating the high interest by institutions for this topic.

The energy saving strategy proposed in this work is obtained by introducing sleep mode and maximum transmission power reduction at the base station side. The sleep mode is the deactivation of the radio stage of the base station equipment in agreement with the requested traffic within its coverage area [18], [19]. The analysis carried out in [20] and [21] highlights that for macro base stations the adaptation of transmission power could be more efficient in order to guarantee also the area coverage.

This work considers a scenario with both macro and micro base stations and aims at reducing the energy waste by means of a joint strategy which considers the macro base station transmission power adaptation and the micro base station sleep mode. The key of this strategy is the use of traffic forecast in order to allow the base stations to know the traffic behaviour in their coverage area. The aptness of forecast for cellular traffic has been already considered in [22] and [23]; moreover, its application in the energy efficiency maximisation has been used to introduce cell sleep mode: in particular in [24] authors apply compressed sensing technique while in [25] and [26] the exponential smoothing technique is evaluated. In both cases when forecasted traffic is low some radio resources are switched to the sleep mode to save energy. With respect to these previous works, the strategy proposed in this paper can be considered an improvement which use the traffic prevision to jointly introduce sleep mode at micro cell level and adapting the maximum transmission power at macro cell level. As highlighted in [26], the forecast approach requires a lower number of switch on/off operations with respect to the procedure which is based on istantaneous traffic measurements; as a result, the control traffic and handover operations are also reduced.

The paper is organised as follows. In Section II the system model and the main considered metrics are described. In

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Section III the proposed solution is presented. In Section IV the results are discussed and Section V concludes the work.

II. System Model

In this paper a heterogeneous network deployment with macro and micro base stations (BSs) on a given playground area S with a homogeneous traffic distribution is considered. The scenario is similar to the one depicted in Figure 1. The base stations are equipped with omni-directional antennas and each of them covers a single macro-cell or micro-cell area.

A. Available Network Capacity

The relation between available resources and capacity can be modelled by the Shannon's formula:

$$C = B\log_2(1+\gamma) \tag{1}$$

where B and γ are respectively the available bandwidth at a certain cell and the downlink signal to interference plus noise ratio (SINR). In order to evaluate the received power at UE, the path loss model derived from Okumura-Hata model has been adopted. In particular for macro-cell we refer to:

$$PL(d) = 128.1 + 37.6\log(d) \tag{2}$$

whereas for micro-cell:

$$PL(d) = 140.7 + 36.7\log(d) \tag{3}$$

where d is the distance between BS and UE expressed in kilometres. The downlink SINR at a given distance d is obtained by the following formula:

$$\gamma(d) = \frac{P_{rx}(d)}{\sum_m I_m + N_0 BW} \tag{4}$$

where $P_{rx}(d)$ is the power received by a generic UE at distance d from BS, I_m is the received power from the m-th interfering BS and N_0 is the power spectral density of additive gaussian noise. Starting from this definition, the average available capacity in the considered area is:

$$\begin{aligned}\bar{C} = &\sum_{i<N_M} \frac{1}{S_i^M}\int_0^{2\pi}\int_0^{R_M} B\log_2(1+\gamma_i(r))drd\theta \quad + \\ &+ \sum_{j<N_m} \frac{1}{S_j^m}\int_0^{2\pi}\int_0^{R_m} B\log_2(1+\gamma_j(r))drd\theta\end{aligned} \tag{5}$$

where R_{min}^M, R_{min}^m, N_M, N_m and θ are the minimum cell range for macro and micro cells, the number of macro and micro BSs in the considered area and the azimuth angle between BS and UE, respectively. The minimum cell range is defined by the network planning with reference to quality requirements for UE at cell edge.

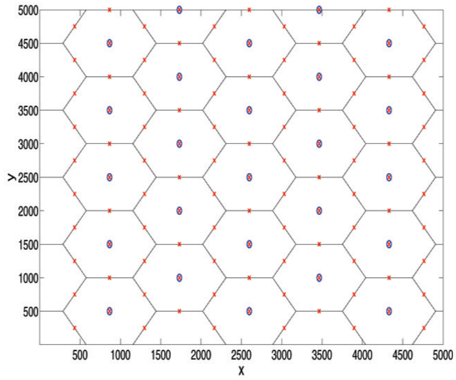

Fig. 1. The considered scenario: the circles are the macro base stations, the crosses are the micro base stations.

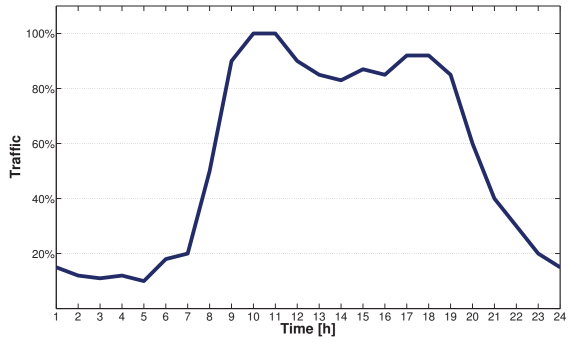

Fig. 2. Daily traffic pattern

B. Traffic Model

In this analysis a dense urban deployment area with a density of about 3000 citizen/km^2 is considered. Assuming that the amount of broadband subscribers is about the 25% of the entire population, the density of broadband users is 750 user/km^2. As suggested by the EARTH E^{3}F [21] 20% of users is active at busy hour and the network has to be dimensioned for at least 150 user/km^2. Each user follows a medium traffic profile requesting 500 kbps for download. The traffic demand in the network is characterized by daily variations that correspond to the traffic profile in Figure 2.

C. Energy Efficiency

The most common energy efficiency metrics are the energy consumption ratio (ECR) and the area power consumption (APC) [27]. ECR is suitable in order to characterize energy efficiency from a service point of view because it measures the power needed to correctly deliver an information bit and it is defined as the ratio of the peak transmission power to the peak data throughput:

$$ECR = \frac{P_{peak}}{C_{max}} \qquad [W/bps] \tag{6}$$

Conversely, APC is the ratio of the power consumption to the considered deployment area and it is an useful metrics the energy efficiency of different network topologies. Therefore, it is used to characterize energy efficiency from a deployment point of view.

$$APC = \frac{P}{S} \qquad [W/km^2] \tag{7}$$

where P is the power consumption of a considered area S. In this paper a metric derived from ECR and APC is introduced in order to evaluate the performance of the proposed adaptive technique:

$$\Upsilon = \frac{P}{C_{req}S} \qquad [W \cdot bps^{-1} \cdot km^{-2}] \tag{8}$$

This metric measures the ratio of the power consumption per area unit P/S to the capacity C_{req} which is requested to the network at a certain time.

D. Power Consumption Model

In macro and micro BTS the power consumption can be modeled as a linear function of the transmission power:

$$P = aP_{TX} + b \tag{9}$$

where the coefficients a and b take into account respectively the effects of power amplifier, feeder losses and cooling and the power consumption which is independen from the transmit power as the one due to signal processing and battery backup. It is has been demonstrated that the transmission power dominates the total power consumption in a macro BTS while in a micro BTS the main terms are due to the effects which are modeled by the coefficient b. In this paper $a = 2.66$ and $b = 118.7W$ have been considered for macro BTS and $a = 3.1$ and $b = 53W$ have been considered for micro BTS [12].

III. Energy Efficiency Optimization

Typically, a cellular network is dimensioned taking into account the maximum requested capacity at the peak hour. Hence the number of deployed base station and their maximum transmission power is able to provide at each time of a day the peak capacity although it is not necessary. In order to reduce energy waste this paper introduces a solution which acts on adapting the number of active base stations and their transmission power with respect to the requested traffic. Particularly, considering the scenario described in the previous section we introduce the cell sleep mode for micro base stations and an adjustment of maximum transmission power of macro base stations. This strategy is based on the fact that in macro BTS the transmission power is the main responsible of total power consumption whereas in micro BTS the major contribution is given by fixed consumptions, i.e. the b coefficient. The proposed solution works as follows:

- hour by hour the number of active micro base station is adapted to the amount of capacity requested by users;
- if the available network capacity is high with respect to the users requests, the maximum transmission power of macro base stations is reduced;
- if the available capacity is not able to satisfy the users' requests, then some sleeping micro base stations are awakened and, if necessary, the maximum transmission power of macro base stations is increased.

It is evident that the key point of the proposed solution is the knowledge of amount of requests at a certain time, i.e. the amount of traffic that the network must carry out. As the traffic in a cell for mobile communications shows a correlation with the hour of the day when it is measured and with the period of the year, the requested network capacity at a certain time can be obtained thanks to a traffic forecast. In this paper we make use of Holt-Winter's technique to perform a daily traffic prediction. The Holt-Winter's forecasting technique is an extension the exponential smoothing strategy which is based on a recursive scheme where the forecast is updated at each observation of the considered phenomena. Exponential smoothing performs the forecast of future values of a time series starting from past values, which are properly weighted, giving to recent values more importance than the older ones. The Holt-Winter's technique (H-W) extends exponential smoothing introducing trend and seasonal components. A $m-$step ahead Holt-Winter's forecast is computed thanks to the following formula [28]:

$$F_{t+m} = (S_t + mb_t)I_{t-L+m} \tag{10}$$

where L is the number of periods in one season. The terms S_t, I_t and b_t are respectively the deseasonalized, the seasonal and the trend components. The deseasonalized component represents the basic level of time series without considering the periodic effects, the seasonal component reflect the variations that recur periodically to the same extent and the trend models the long-term movement in a cyclical context. This components are computed as follows:

$$\begin{aligned} S_t &= \alpha\left(\frac{Y_t}{I_{t-L}}\right) + (1-\alpha)(S_{t-1} - b_{t-1}) \\ I_t &= \beta\left(\frac{Y_t}{S_t}\right) + (1-\beta)I_{t-L} \\ b_t &= \gamma(S_t - S_{t-1}) + (1-\gamma)b_{t-1} \end{aligned} \tag{11}$$

The initial conditions are:

$$\begin{aligned} S_t &= \sum_{t=1}^{L} \frac{Y_t}{L} \\ b_t &= 0 \\ I_t &= \frac{Y_t}{S_t} \quad for \quad t = 1...L \end{aligned} \tag{12}$$

where Y_t is an observed values of the considered time series at time t. The terms α, β and γ are respectively the overall smoothing parameter, the seasonal smoothing parameter and the trend smoothing parameter that have to be tuned in order to make the error between real and forecasted values the lower as possible. In Figure 3 the forecasted traffic is evaluated with reference to the observed traffic during a week.

As shown in equation (9), the power consumption of a base station can be modeled as a function of the transmitted power. Therefore, the knowledge of the instantaneous requests of traffic in a certain area allows to save a lot of energy by putting micro base station in sleep mode and setting the transmission power of the macro base stations so that the capacity needed to satisfy the requests is provided. Since a BS cannot have the perfect knowledge of how many traffic requests happen instantaneously in its area of coverage, the proposed power saving solution makes use of the Holt-Winter prediction algorithm presented in equations (10), (11) and (12). As a matter of fact, thanks to the Holt-Winter's forecast technique each day is modeled as a season composed by $L = 24$ periods, i.e. the hours. At the beginning of the day the daily forecast is computed and each hour the transmission power is adapted in order to guarantee the requested capacity. In particular, the proposed algorithm works as in the following:

- During the initialization stage, that should be at least one season, the macro BSs record the traffic provided during the time interval by itself and by the micro BSs within its area of coverage and sets up the starting values of the deseasonalized, trend and seasonal components (H-W components) as explained in (12).
- After the initialization stage, at each hour the H-W components are updated taking into account the new values of the recorded traffic.
- The forecast is computed at the beginning of each day considering the latest values of the H-W components.
- If a traffic forecast is available, at each hour the macro BS considers the forecasted values as the reference capacity that has to be provided to its area of coverage for the successive time interval. On the base of this value the capacity is adapted, putting in sleep mode or waking up the micro BSs within its area of coverage and reducing or increasing its transmission power.

Before showing the simulation results for this technique in a typical cellular scenario, some points have to be further clarified. First of all, the set up of the transmission power of a macro BS is driven basically by coverage needs during the network deployment stage. So, if we act on this value we must be sure that the coverage area is not modified. For this reason a power range has to be fixed, with the minimum value required to provide the coverage of the area assigned to the cell at the lowest available modulation and coding scheme: this value can be selected as the transmission power lower bound. As for the upper bound, this value is related to the maximum transmission power which allowed to the the BS. The proposed strategy is able to run in a decentralized way at each BS of the considered network without any signalling need between the macro BSs. In particular the forecast is evaluated for each cell and the parameters α, β and γ of the H-W algorithm could be adapted during the algorithm execution by minimizing the error between the recorded traffic and predicted values during the previous evaluation.

IV. Results

The solution described in Section III has been tested for a typical deployment scenario thanks to a simulator built in the Matlab environment. The simulator is able to generate the amount of requested capacity for the considered area starting from a weekly traffic pattern like the one shown in Figure 3.

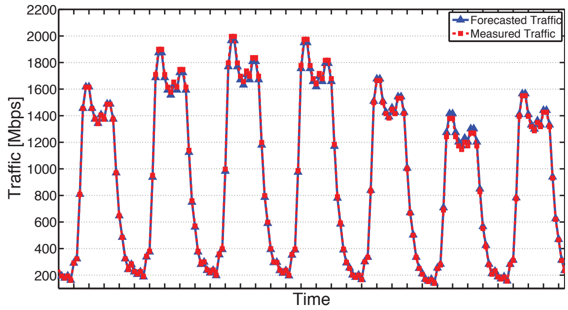

Fig. 3. Measured versus forecasted traffic over a week

TABLE I
SIMULATION PARAMETERS

Carrier frequency	2 GHz
Bandwidth	5 MHz
Transmission Power	Macro BTS $\{5 \dots 20\}$W Micro BTS 5W
Path loss model	Macro Cell $128.1 + 37.6 \log(d_{km})$ Micro Cell $140.7 + 36.7 \log(d_{km})$
User data rate	500 kbps
Traffic distribution	Uniform
Thermal noise	-174 dBm/Hz
Noise figure	10 dB
Inter syte distance	Macro BTS 1000 m Micro BTS 500 m
Playground area	5 km $\times$ 5 km

After a training phase where the parameters of Holt-Winter's technique are initialized, the forecasting is computed and the adaptation of the transmission power of each base station is performed. The training phase must be at least one season, i.e. one day of traffic. All simulation parameters are summarized in Table I.

The main effect of the proposed algorithm is the adaptation of the macro base stations maximum transmission power and the number of active micro base station with respect to the requested network capacity. Figure 4 and Figure 5 show how this purpose is reached, considering a week as observation time. The macro base station transmission power has daily fluctuations between its maximum and minimum allowed values and the number of active micro base station is adapted hour by hour to the daily and weekly traffic variations in agreement with the values of forecasted traffic.

The consequence of power adjustment and sleep mode introduction is evident in Figure 6: the micro base station and the macro base station power consumption are dependent on the maximum macro BTS transmission power and the number of active micro BTS, which depend on forecasted traffic in the network. Therefore, the global network power consumption can be made dependent on the global traffic thanks to this adaptive strategy.

Finally in Figure 7 the behaviour of normalized Υ function

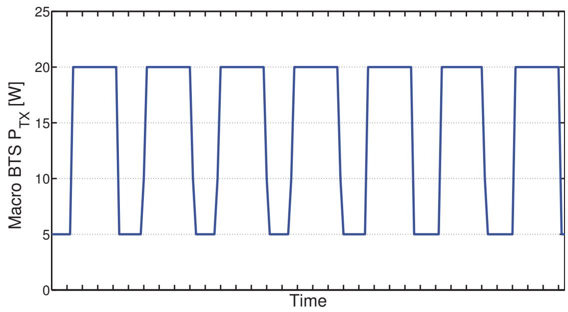

Fig. 4. Maximum transmission power of macro BTS during a week

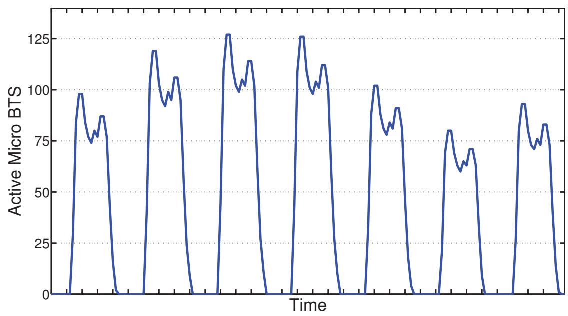

Fig. 5. Active micro BTS during a week

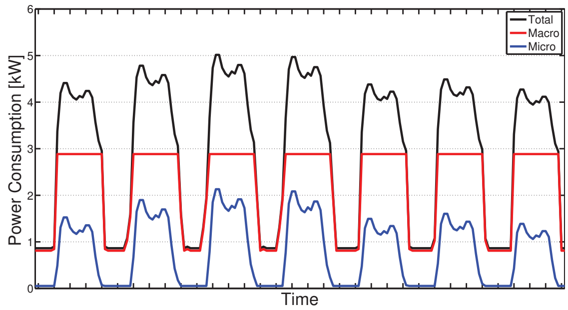

Fig. 6. Power consumption of the considered network during a week

is shown: particularly, the proposed strategy is compared with the no energy-saving approach, highlighting the increase in energy efficiency due to the adaptive technique based on traffic forecast. Moreover, in the same plot also the error between the forecasting technique and the theoretical optimum is reported for comparison: the latter strategy is based on an instantaneous perfect knowledge of the traffic in the network, and the represent the lower bound for an energy saving strategy which aim at affording a QoS requirement. As higlighted by the very low value of the error, the traffic forecast is very close to the optimum strategy.

V. Conclusion

In this paper the energy efficiency optimization of a cellular network has been presented. The considered network is composed both by macro cells and micro cells, so the optimization can be carried out working on two level: the first level of optimization is the introduction of micro base station sleep

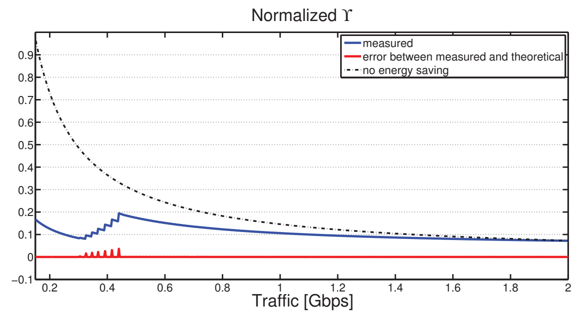

Fig. 7. Normalized Υ function versus traffic

mode and the second level is the adaptation of the maximum transmission power of macro base stations. The sleep mode is allowed only for micro BTSs because macro BTSs have to guarantee the coverage of the considered area. The number of active micro base stations and the value of macro base stations transmission power is driven by the capacity requested by the network, i.e. the traffic level. The key of the proposed algorithm is the use of traffic forecast in order to allow the base stations to estimate the future value of requested capacity. The use of traffic forecast is justified by periodicity of resource requests on a daily and weekly base. The forecast is obtained by the Holt-Winter's technique which is based on exponential smoothing for time series. The algorithm has been tested in a typical network with macro and micro cell coverage. Results show that this technique make the network power consumptions strictly related to the effective requests of traffic with performance very close to the optimum case.

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